The Hungarian Lowland and its Effect on Bridge Design

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1. The Great Hungarian Plain

(in Hungarian Nagyalföld) is a geographical unit in the Eastern part of the Carpathian Basin. The East-West and the North-South extent of the region are about 300 km both. The total area of Nagyalföld is about 100,000 km². The Hungarian part of the Great Plain is 52,000 km² (see Fig. 1) while the rest belongs to neighboring countries.

The land is flat plain; its altitude over sea level is between 85~100 m except some smaller regions. There are a number of hot water spas -- most famous of them is Hajdúszoboszló and Gyula -- based on artesian wells as the geothermal gradient below the Plain is much higher than in the rest of Europe.

The main river of the Plain is Tisza [1, 2] with a total length of 966 km and with a watershed area of 157. 186 km² (see Fig. 2). Its yearly average water output is 820 m³/sec. This output, however, is greatly fluctuating (up to 35 times). The range of tide between actually measured maximum and minimum is 11.73 m at Szeged. The gradient of the river on the middle and lower part is small, only about 3. 4 cm/km. The Tisza Valley can be divided into three sections:
- Upper Tisza Valley;
- Middle Tisza Valley;
- Lower Tisza Valley.

Most of the area is arable and the agriculture grows cereals, vegetables, fruits. A part of the area is supplied with irrigation canals. Animal husbandry is also remarkable, based on the abundant corn crop. The Hortobágy and Bugac Puszta was declared National Park with the aim to preserve their natural environment.

Although the Nagyalföld is flat plain, only a half of it can be regarded lowland.
Figure 1.

Eastern Hungary
Terrain & Rivers
1:1250 000
Our study covers mainly the regions of Nagykunság, Hortobágy, Jászság, the territory between Berettyó, Körös and Maros Rivers in the Middle Tisza Valley and the Hungarian Lower Tisza Valley (see map on Fig. 1). This area is over 25,000 km², constituting the features of a lowland.

1. The River Tisza collects almost all the rivers and creeks in the Eastern part of the Carpathian basin while finding its way in the Great Plain (Fig. 2). The most important tributary is the Szamos. It has a great influence on the hydrological properties of Tisza. The Tisza’s watershed area is increased by 37% by Bodrog and by 35% by Hármas-Körös so they have remarkable influence too. Similarly the effect of Sajó and Maros cannot be neglected.

The terrain of the watershed area is mainly impermeable or semiimpermeable. This means that the flood-tides of the river are high, however, the water resources drain out soon, so the water output tends towards extremities. This is why the Hungarians regard River Tisza as capricious.

The meandering Tisza occupied wide and great territories before regulation. The soil was marshy, and only the locals could find their way on the willow-grove floodplain among inundation. The regulation started with the mapping of the river in 1820-1830 years. The aim of regulation was to increase the gradient of the river and this way to accelerate the passing of the floods, and to protect the arable land. The regulation meant to cut through the meanders and to build dikes at the same time. The construction works began in 1846 with greater intensity.

The average gradient of Tisza was increased by the 37% shortening of its length on the Great Plain (see Fig. 3). The hydraulical balance of the river was upset by the regulation and this has led to the deepening of the river bed and erosion of the banks that needed further intervention. Also the level of floods -- now kept within dikes -- rose. (Total length of dikes was 3168 km.) It lasted for decades till the dikes corresponded to the requirements of the new higher level floods.

The dikes prevent great areas from inundation but at the same time prevent drainage by seasonal brooks so polders were formed. Therefore it was important to dig drainage canals for the polders right after the flood prevention. The biggest result of regulation was to protect 2,302,000 hectares -- ~25% of the present territory of Hungary -- from the floods of River Tisza, most of it for the safe agricultural production. (We can evaluate the great extent of regulation when we consider: both
the length of dikes and the size of protected area exceeds those of The Netherlands.) Today the flood control is still of great importance and a crucial point is the top level of dikes. The Standard Highest Water Level (SHWL) was calculated by statistical analysis based on water-gauge readings. The top level of dike is determined by SHWL plus a safety margin. Today the dikes should safely withstand a flood-tide of 1% probability.

Meanwhile the irrigation became an other important goal as the drought caused severe damages in some years. Irrigation was started in the Körös Valley and was developed elsewhere step by step. Irrigation was based on pumping stations and / or dams on the rivers. The first dam (with purpose of irrigation) was built on Hármas-Körös at Békésszentandrás in 1942. The next one on River Tisza at Tiszalök was finished in 1955 together with the great irrigation Eastern Main Canal. The Kisköre dam was finished some 20 years later. The size of irrigated land is well over 200,000 hectares today.

1. 2 Geological and geographical features [1] show that the Great Hungarian Plain has crystalline or mesozoical stratrum that is in about 1700—2800 m depth, but the greatest depth is below 3800 m near Hódmezővásárhely. This is covered by thick recess sediments of Pannonian Sea and of alluvial deposits in Pleistocene (100—650 m) and Holocene (10—20 m). A small area to the North-East is subsurface volcanic area while the superficial volcanic area reaches River Tisza at Tokaj town.

In the Upper Tisza Valley, (see Fig. 1), the altitude of land between Rivers Tisza and Bodrog as well as between Rivers Kraszna, Szamos and Tisza is 93—118 m over sea level. The majority of soils are Holocene sediments with Pleistocene sand islands.

The Middle Tisza Valley from Tokaj town to the mouth of Körös river (see Fig. 1) is a plain of fluvial deposits, but not a homogenous unit, divided into sub regions. Taktaköz is on right bank of Tisza (see Fig. 1). Its surface is covered by fluvial clay, silt, sand and silty loess. It was a flood plain of Tisza before the regulation, and the lowest part (93—94 m) is marshy meadow even today.

Borsod-Heves Region consists mainly alluvial deposit (clay), partly covered by fluvial silt and loess. Its surface is uneven to N—E, while the western half is tediously
flat (86~93m).

Jázság is on the right bank of Tisza. It is a flat plain with 104~87 m altitude. The slope is only 17 m on a 50 km distance. Its main river — the Zagyva — has a gradient of 9 m on 60 km length (15 cm / km). It was a marshy meadow until the river regulations in the last century. The area has been constantly sinking until now (38 ~118 mm in 40 years), and it is relatively active seismologically.

Hortobágy Puszta is on the left bank of Tisza. The area is 2300 km² with an altitude of 88~92 m above sea level. It is a very flat land like table. The soil is clay, silt and silty loess. The Tisza River had many beds at Hortobágy Puszta during the Holocene, in one of them flows now the Hortobágy River. The silty loess surface got saturated with soda as a result of increase of alkali concentration due to rising water table and evaporation.

Nagykunság is on the left bank of Tisza River almost in the center of Great Plain. The area is 3250 km² with an altitude of 85~92 m. The surface is monotonous except for sand-drifts. Unlike the Jázság, the Nagykunság did not sink in Pleistocene and Holocene. This is why the fine grained sediments are thinner than elsewhere. The surface was formed not only by rivers but the wind too. The Tisza River appeared on Nagykunság during Holocene and started to transform the land. The sandy hillocks were washed away and silt, sandy silt and silty clay were deposited instead.

The Lower Tisza Valley (see Fig. 1) is an area of about 2000 km². The altitude is below 85 m over sea level, with little exception. It was the flood plain of Tisza River before the regulation. The substratum is in great depth. The thickness of Pleistocene sediments is 650~550 m, consisting of medium grain sand and finer grain soils. The surface is Holocene sediment of 10~20 m thickness and the closer is the surface the finest is the soil.

The Körös region (see Fig. 1) is perfect plain, the gradient from Hortobágy till the deepest point is only 7 m on 24 km. The landscape did not change much from the beginning of Holocene until the river regulations: marshy meadows, swamps and meandering streamlets were dominant. The Körös Region was the main recipient of fluvial sediments during Pleistocene and Holocene. The surface is silty loess, silty clay and clay. There is also peat in some places.

The region between Körös and Maros Rivers (see Fig. 1) covers an area of about 5000 km². It is a plain built up of young sediments, having an altitude from 100~110 m to 83~85 m EastWest. The substratum is in great depth covered by thick marine deposits (mainly clay), by fluvial deposits (sand clay and silt).

1.3 The climate of the Great Plain [1,2] is hot and dry. The cloudiness is minor, it is around 50 % in yearly average. The yearly sum of sunny hours is 2000~2200, less in winter and plenty of sunshine is in summer.

The temperature shows great fluctuation. The winter is cool, the mean January temperature is around -2° with ~30 winter days. Spring starts early. The mean temperature of July is ~22°. The number of summer days is 75~90 and that of the
Figure 4. Average Yearly Precipitation in Hungary and an Eastern Carpathian Basin, in mm [2].

extreme heat is 20~30. The Autumn is long and warm.

The prevailing wind direction is different in each region due to the relief of surrounding mountains. The average yearly rainfall is around 550 mm and it is about 500 mm in the Szolnok-Mezőtúr region and in Hortobágy Puszta (see Fig. 4). Most rainy is June with 55-70 mm monthly average and less rainy is January with 24~35 mm monthly average. There could be a second peak in the rainfall in the Autumn. The Winter is generally short of snow. The yearly fluctuation in precipitation is great so we can find great difference between the rainfall of wet and dry years.

1.4 The most important hydrographical feature of the Alföld is the shortage of water. The little precipitation, and the big evaporation results in very small specific yield (< 0.5 l/sec. km²) and runoff coefficient (3~5 %). The rain evaporates right from the surface.

The Alföld was rich in stagnant water before the regulation of Tisza as the floods of Tisza and its tributaries filled up the depressions regularly in each year [5]. The regulation and the network of drainage canals have put an end to this situation. Today the total surface of lakes is less than 1 % of the area. These lakes are mainly artificial ones for fisheries or ox-bow lakes.

The flat and smooth surface covers an interesting variety of underground waters. The deep underground layers accommodate medicinal waters over 70°C temperature. A great number of deep bored wells provide hot water for spas. These wells are 1300~2300 m deep in Pannonian sediments. Many wells provide drinking water to the settlements. These are in 200~260 m depth in Pleistocene layers. This was necessary
as the subsurface water on the whole Great Plain has high salt concentration of $>1000$ mg/l (locally 6000 mg/l).

The subsurface water table is generally near to the surface. The highest is the water table in Taktaköz, Borsod–Heves Region, Hortobágy Puszta, and in the alluvial fan of Sebes Körös its depth is $<3$ m. In other regions it is $3\sim5$ m. There are many water tables above each other in some regions as a result of configuration of permeate and impermeable layers. The periodical fluctuation of ground water table level is only $2\sim3$ m in Taktaköz, Borsod. Heves Region, central Hortobágy Puszta, and $3\sim6$ m elsewhere.

When we compare the depth of ground water table and its periodical fluctuation, we can reach a conclusion that the whole Great Plain is threatened by inundation of ground water in wet years. This is neutralized by dense drainage canal network.

The Hydrography of the Körös Region is determined by the Körös river system. It consists of five rivers that spread like a fan. The rivers are Fehér-Körös, Fekete-Körös, Sebes-Körös, Berettyő and Hortobágy-Berettyő main canal. The Körös Region was the biggest marshland in Hungary before the river regulation.

The Hármas-Körös has a watershed area of 27,538 km². It is impossible to find the main stream because there is no big difference among the five rivers either in length or in size of watershed area or in water output. The biggest changes were made in this river system during the regulation.

The specific yield is small in the region and the runoff coefficient is the smallest. This is why water is conducted from Tisza to the region through Keleti-Főcsatorna and Hortobágy-Berettyő main canal.

2. Bridge Engineering on the Great Plain.

There is practically no construction material in the region of Great Plain. The only exception is brick -- that is plenty -- but it is not used in road or bridge building. Even earth means a problem many times when building embankment. Sand, gravel, crushed stone, cement, timber, steel should be transported from a distance of 100–300 km. The Great plain has initial disadvantage in construction activity as nearly all the building material has to be transported there. It means an increase of costs. This way the general requirement of material economizing gets a more pressing impetus.

Discussing the bridge engineering in the Great Plain we have to mention that all the road and railway bridges over Tisza River were destroyed during the World War II together with many bridges on other rivulets. The reconstruction was completed by 1950 by building permanent or semi-permanent structures. Later the semi-permanent structures were replaced by permanent ones (e. g., at Tokaj, Szolnok, Kiszár over Tisza). The digging of new irrigation canals made necessary the construction of new bridges too (Keleti Főcsatorna and later on the Nyugati Főcsatorna). The great development of automobilism had started 35–40 years ago, so it generated an urgent need for road and bridge improvement. The main task for this period was to deal with
bridges of narrow roadway or of inadequate loading capacity or of both. Those bridges that could not have been widened or strengthened (e.g., through type structures) were replaced by new ones like a dozen new bridge on Körös river system, on Berettyő, Zagyva, Kraszna, Szamos. Also the bridges of combined road & railway uses were to be relieved by building a separate road bridge nearby (e.g., at Tiszafüred, Algyő over Tisza).

The post war state road network was dense enough but it had a number of deficiencies. The roads were narrow with poor lining and mainly with traditional macadam surface coarse of inadequate load bearing capacity. So the road widening, the improvement of lining (cutting of sharp curves), the thickening of pavement by asphalt course was a long lasting task. Consequently the bridges had to be widened and reinforced too on these roads. Overpasses were built above railway lines to eliminate dangerous crossings. The expressway construction began in the 1960–ies in Hungary but it did not concern yet the lowland region. Nevertheless the bypasses and new urban sections of state roads resulted in building new bridges over Tisza (Szeged, Szolnok) and other streamlets, ox-bow lakes, as well as new flyovers above railway lines of heavy traffic.

2. 1 The approach ramps to bridges are generally roads on embankment in Hungary (except in urban region where generally no space is available). This practice is based on economy as the bridge is more expensive than the road on embankment.

In our study we proved that

- a little increase of the embankment height results in a sharp growth of the embankment volume, as it is on Figure 5, (increase in expense of excavation, transportation and compacting price);
- a higher embankment needs wider slopes (increase in cost of land purchase);
- bigger embankment needs bigger area earth pit as the depth of the earth pit cannot be bigger (due to ground water table or change of soil quality); this results in higher land price, too.

The height of the approach embankment depends on many factors. One of them is the level of terrain compared to the highest water level and the clearance above the highest and the navigation water levels. Also the levels of dike-crowns should be taken into account. When crossing a railway or road, similar factors are to be considered. Nevertheless, the construction depth of the bridge has many times a direct effect on the height of the approach embankment. This is one more reason why the construction depth of a bridge in a lowland area should be thoroughly considered
during the design.

2.2 The abutments of small bridges [3] show a steady development. The traditional gravity abutment acts as a retaining wall that bears also the load P from the superstructure. The strutted abutment is joined to the superstructure by hinges so the superstructure props both abutments in horizontal direction (Fig. 6). The G self weight of ascending wall is smaller and the R reaction can be centric although inclined. The strutted abutment on pile foundation can be regarded as a vertical cantilever with a hinge on the top. The design proved to be successful. The present bridge engineering practice [4] uses the strutted abutment up to 15 m span length, but allows it up to 25~30 m span length under favorable circumstances. The masked abutment or stub abutment is nothing but a pile cap on a single line of piles (Fig. 7). There is no need to build wingwall, the pile cap is mostly covered by earth. The semi-masked abutment has a slightly bigger height with wingwall.

The frame-abutment (or spill-through abutment, see Fig. 8) of medium span bridges is a closed frame, embedded in the soil of approach ramp. Frame-abutment is designed generally on pile foundation in the Alföld. It is used mainly in flyovers and the RC structure is cast in place. This type of abutment is suitable for structures of 20~30 m span lengths and 60~90 m total length. Bigger structures -- for example bridges over river Tisza or Körös -- are designed with traditional type abutments.

The above abutment types have favorable features. The earth pressure is reduced or eliminated, so the reaction force is less on the foundation. This is better for poor subsoil. There is no need to deal with dewatering (stream or ground water). The bigger clearance for stream allows unobstructed flow without local increase of speed and whirlpools, which is safer against scour. The formwork of abutment can be simple.
for concreting. On the other hand, the superstructure should be longer, but it is more easy to build, using prefabricated beams or advanced technologies. The slightly longer span might result in a more economical bridge or at least not a remarkable increase in expenses.

Behind the abutments compensating slab is built. The compensating slab or approach slab is supported on the abutment by its front edge while the rear end follows the settlement of embankment. This way it distributes the unavoidable settlements along its length. This results in a slope on the pavement rather than a dangerous bump for the traffic (Fig. 9).

2.3 Foundations. Direct Foundation needs specific soil condition that is seldom met on the discussed lowland area of Great Plain so it was scarcely designed there. Pile Foundation proved to be very reliable in bridge engineering practice. Old pile foundations probably have a great reserve in load rating[7]. Senior engineer’s opinion was that the number of applied piles exceeded the required number by 25～30 % or even more. Extensive research in the latest decades has led to a better understanding

Figure 8. Scheme of Frame-Abutment.

Figure 9. Scheme of Compensating Slab.
of the phenomenon. *Petrasovits* [6] corroborated foreign research results stating that the \textit{tip resistance of a driven pile turns constant after a certain depth}. This depth is about $20 \sim 25d$, where \(d\) is the diameter of pile. \textit{Under this depth the ultimate load of a pile is increased only by the skin friction increment} (on a bigger surface). So the ultimate load of a pile may be increased by a bigger length but \textit{it may not influence the settlement of the pile}. The most important results of practice, experiments and theory are now comprised in the standard specification for foundation design [8], but still there are open questions as the participation of pile cap in the load bearing capacity of footing. It is excluded now as a rule when dimensioning the pile foundation but some research shows that its share is as big as $15 \sim 30\%$ of the total load. Nevertheless, when we think of the cases of scour we are not willing to take this effect into account.

The bridge design is always preceded by \textit{geotechnical investigation}, including borehole sections, testing the soil samples of layers as well as small diameter \textit{driven penetration probes}. The experience has shown that the penetration probe is indispensable to design the pile length. Only the probe diagram -- showing the variation of resistance against penetration of different soil layers -- gives a great probability for the length of pile. Also it can give a basis to approximate the ultimate load of a pile. Although our experience in the lowland area shows that \textit{our piles are of friction type}, we like to place the pile tip in a layer that shows a bigger resistance than the others. Generally we do not go very deep with prefabricated RC piles. The usual depth is $8 \sim 12$ m for small bridges. The limit load is estimated on the results of penetration probes and it is checked when driving the first piles. In case of medium bridges and of questionable circumstances, \textit{pile test loading is made} many times. This is the most exact and safest way to establish the \textit{ultimate load} on a pile and calculate the limit (allowable) load. It gives also a good estimate for the possible \textit{settlement} that is also quite important in lowland area when building multi-span continuous slabs or beams as we usually do. In this conservative design are \textit{still a number of uncertainties left, such as the group effect in silty or clayey soils, the alteration of soil layers or their properties, etc.}

\textit{Larger diameter} piles were made in the lowland area by \textit{Franki, Benoto and Soil-Mec} methods. Among them, the Franki and Benoto piles were used only in a few cases but the Soil-Mec was frequently used at greater span structures.

The \textit{Soil-Mec} (Italy) \textit{large diameter pile} diameters are 0.8, 1.2 and 1.5 m. Maximum pile length with standard equipment is 44 m. The protection of bore-hole against collapsing is made by high density supporting Bentonite mud and by steel casing. Piles can be made either in dry conditions or in river bed.

In the latest 20 years, parallel with the applications, experiences were collected, research was made. \textit{Prof. Farkas} of BTU wrote a comprehensive study about them recently [9] as a number of questions are still discussed on international level.

The results show that the friction resistance grows quickly with loading and
reaches its maximum at about $s = 0.01D$, where $s$ is settlement and $D$ is pile diameter. The tip resistance grows slowly and develops at about $s = 0.1 \sim 0.25D$. The results are in agreement with foreign ones. As the maximum values of skin friction and tip resistance do not develop at the same settlement values, it is questionable to simply add them up when calculating the ultimate pile load and the allowable load (see Fig. 10).

It is well known that the settlements of large diameter bored piles are bigger than that of traditional piles. This is why the 9th European Conference of Soil Mechanics and Foundations suggested to define the ultimate pile load as the load belonging to the $s = 0.25 \sim 0.30D$ settlement. Prof. Farkas thinks that the old concept of finding the allowable load through dividing the ultimate load by a safety factor is questionable.

It could be more correct to start from the allowable settlement of the superstructure. Nevertheless, the Hungarian practice regards the load coupled with 5 mm settlement as limit pile load in most of the cases.

The test loading of a great diameter bored pile means a great cost and remarkable technical difficulty because of the great load. The ultimate load can be well over 10 MN. In spite of the troubles, it is made at each site. In some cases the traditional loading arrangement was applied with anchor piles and "loading bridge" between them over the test pile. An other solution was to place the test pile under the abutment and the loading was to be performed against the mass of the abutment. Recently the VUIS-P test loading system is applied (Fig. 11). The method is technically easy so it is economical. The tip resistance and the skin friction on the lower section are balanced by the skin friction on the upper part of pile. Research shows that
the test loading results are on the safe side (giving a bit smaller values than the real pile capacity).

The group effect of large diameter bored piles is still not perfectly clear. Very probably a group of such piles would show smaller ultimate load for one pile than a free standing single pile. Also the settlement of a group of large diameter bored piles is bigger than that of an individual pile by even ten times. The relevant formulas are based on few results so they are still unreliable.

The large diameter Soil-Mec pile foundation proved to be reliable and it was used at five bridges over Tisza River. [10, 11, 16, 17].

Other Kinds of Foundation are seldom used in the lowland region. The last pneumatic caisson bridge foundation on Tisza River was made 48 years ago. Open caisson (well) was used sometimes in the nineteen fifties in the Eastern Main Canal bridges.

The bridge over Hármashől River at Kunszentmárton [13] (Fig. 12) had caisson foundation at pier #3 and direct foundation at pier #2, as the original plan was modified. Ten years later the bridge showed great unequal settlements (in the range of 81~115 mm) that harmfully influenced the inside forces. To restore the original state, the lifting of the structure was decided at some supports. Authors think that the foundation method as well as the mixture of techniques was not the best choice at the given site with so poor subsoil.

2. 4 The superstructure of a small span bridge is always made of RC slab. The shape of slab in plan is rhomboid as the intersections of axes of the road and the streamlet
are seldom rectangular, so skew bridges are dominant.

The traditional way was to build cast-in-place RC slab on falsework supported formwork. Nevertheless, it was manpower consuming and expensive. Seeking faster and cheaper techniques, partial prefabrication of slab was developed [4]. The inverted T section RC or PC beams substitute for the falsework and bottom formwork (Fig. 13/a). The skew angle can be any between 30° and 90° and the span length can be 2~10 m. The width can vary without limit.

In a new design flat U shaped beams are placed side-by-side [4] (Fig. 13/b). The interaction with the cast-in-place concrete is ensured by the jags inside the U shape. The same jagged surface prevents the uplift of cast-in-place slab from the precast beams. This 20 cm thick slab with reinforcing mesh at the top and bottom ensures the distribution of concentrated live load and crosswise rigidity. The span range is 4~14 m.

The superstructure with precast beam integrates the advantages of prefabrication with those of cast-in-place slabs.

Two series of precast PC beams were developed for bigger spans. The EHGE series was used for span range 10~22 m and the EHGT series for span range from 10 m to 30 m [4] (Fig. 14). The beams had composite interaction with the 20~25 cm thick slab on top of them by means of protruding stirrups. The thin web and small size lower flange resulted in a relative light superstructure.

Recently a new type precast PC beam of U cross section is used [4] (Fig. 15). Although the beams are more heavy, they are more stable against transportation and erection. The design principle is the same, concerning the interaction with cast-in-place slab, the lack of floor beams, the way of continuity for live load.

Besides the precast PC beams, there is room for individual design. Examples were the flyovers on the bypass of road #4 around Szolnok city built by the incremental launching-in technology. An other was the Berettyő Bridge at Berettyőszentmárton village [7], a three span steel-concrete composite bridge.
The composite bridge at Csenger village had precast slab units during erection. The patented double concrete flanges composite bridge is light and the construction is extremely fast with the precast PC slab units (Fig. 16).

When the Eastern Main Canal was constructed, twenty through type bowstring arch road bridges [14] were built over it. As the navigation had required a remarkable clearance under the bridge, the reduction of structural depth gained great importance in the design.

The designs showed a steady development. In the first design the deck structure was made of 18 cm thick RC slab, supported by a grid of stringer and floor beam. The structural depth was 125 cm. The tie of arch was made of spiral cables of external position. The construction process was troublesome and delicate. Also the tie cables were not properly protected against corrosion, so the design was modified.

In the second design the stringers and floor beams were omitted and a 44 cm thick flat slab was built instead. The falsework and formwork were more easy to make and also the structural depth of bridge was reduced to 49 cm. The tie cable was placed in a duct in the sidewalks filled later with concrete. Nevertheless, the delicate process of building the arch and stressing the tie cable remained approximately the same and the construction joints caused maintenance problems later.

Figure 16. Double Concrete Flanges Composite Bridge [4].

Figure 17. Bowstring Arch Bridge on Eastern Main Canal [4].
Legend: a) longitudinal section, b) profile, c) section A-A and B-B, d) plan of abutment, e) plan of bridge.
The third design (Fig. 17) eliminated all the remaining construction and maintenance problems. The 44 cm thick flat slab was post tensioned by Freyssinet cables. This PC slab as a whole was acting as a tie to the arch. The slab was constructed first and it was followed by the building of arch. The Freyssinet cables were grouted, providing usual corrosion protection. The span lengths of the 20 bridges were between 47.30 m and 60.45 m.

Five deck type PC girder bridges were built on different branches of Körös River system [12, 13, 15]. The main span length varied from 72.00 m to 85.80 m and the total length from 172.10 m to 234.44 m. The bridges had haunched lining with a minimum structural depth of 1.93〜1.98 m in the center of main span. All the bridges were free cantilevered using precast concrete segments. There were settlement problems with the Kunszentmárton Bridge -- described earlier -- but the other bridges were founded on Soil-Mec piles and no such problem occurred. Although a heavy PC bridge is not the best choice for the Alföld region of poor subsoil, we have to add that the bridges gave a positive impact to the development of concrete bridge engineering.

The road bridges over Tisza River show a great variety in structure and construction technology. The bridges at Tiszafüred and at Kisar were trough type Warren truss. In spite of the modern design, these trusses did not show particular economy in steel consumption (e.g. 346 kg/m² at Tiszafüred bridge).

A steel-concrete composite girder bridge was built at Algyő village in 1974 (Fig. 18). It was the biggest span composite structure of Hungary nearly for two decades with 102 m main span. The concrete slab was post-tensioned over the inside supports by Freyssinet cables and jacking the outside supports. The bridge was quite economical in steel consumption: only 182 kg structural steel, 48 kg rebars and 15 kg prestressing wire was used for one square meter of deck.

Steel structures with orthotropic deck plate were successfully used over Tisza River. Three bridges were built with such a design. First of them was the Bridge at Szolnok city on the old stretch of main road # 4 with 79 m main span. This moderate size superstructure was a kind of experiment to gain experiences about fabrication,
erection and maintenance of orthotropic steel decks for future bigger span bridges over Danube and Tisza. The structure was very successful and economical (314 kg steel for 1m², 10% less than Tiszafüred Bridge). After three decades under heavy traffic no major repair was needed, except for the periodic repainting and renewal of asphalt wearing course.

The Northern Tisza Bridge at Szeged City [11] (Fig. 19) was put in service in 1979. The total length of river bridge without approaches was 372 m with 144 m main span. The steel weight for 1m² of deck was 353 kg. The average dead load of superstructure was 544 kg/m²; this is very light, about the half of a steel-concrete composite bridge. A couple of years after the bridge was put in service, the asphalt pavement started to get wavy. This is a typical "sickness" of orthotropic steel decks although it was not experienced at Szolnok Bridge. The wearing surface had to be repaired. The bridge with its 144 m main span is still the biggest plate girder bridge of Hungary.

The third orthotropic steel deck plate girder bridge was built over Tisza River at Polgár Town. It was opened for service in 1991.

The first prestressed concrete bridge over Tisza River between Csongrád and Szentes cities was finished in 1981 [16]. The total length of the bridge is 509.80 m with a main span of 93.00 m. The cross section of the main bridge is single cell box section. The foundation is friction type Soil-Mec pile with 20~25 m length. The approach bridge over flood plain was made of precast PC beams while the main bridge was built by balanced cantilever method using traveling formwork.

The most recent PC bridge over Tisza River is on the bypass of main road #4 around Szolnok City [17] (Fig. 20). The single cell box cross section bridge carries two lane roadway that is skirted on one side by cycle path and sidewalk. The 675.60 m long bridge has a main span of 120.00 m. The structure was composed of three parts: the main bridge was built with cast-in-situ balanced segmental method using traveling formwork. This was jointed continuously to the approaches. The approach bridge over the flood plain was made at the abutments in segments and was jackeded in horizontally to its final position by incremental launching technology. The bridge stands on Soil-Mec piles of 120 and 150 cm diameter. The pile length varies among 20.0 m and 32.0 m. The bridge was opened for traffic in 1992. It is now the biggest span PC girder bridge in Hungary.
The PC bridges are rather heavy, the Szolnok Bridge has a dead load $\sim 2.9 \text{ t/m}^2$. This is $\sim 5$ times the average dead load of an orthotropic steel deck plate girder bridge. The big dead load needs more piles and bigger pile caps. The increase in pile number is not linear because of the different subsoil conditions and the group effect (which we do not know exactly). At the same time, the load on a single pile does not vary in function of the dead load of the superstructure, as the dead load plus live load influences the number of piles. In both cases -- that is both for light and heavy superstructure -- we obtain pile groups with smaller or bigger number of piles and with about the same load on an individual pile. The problem comes from our limited knowledge: we do not know if there is any difference in settlement of the above mentioned two large diameter pile groups. Now we assume that there is none. This means that the overall economy of the PC and orthotropic solutions compete together with the other technical aspects and there is no specific argument against the heavier solution. There is one point, however, which is many times overlooked: if settlement occurs later and the structure should be jacked up, this can be made more easily on a light steel structure than on a heavy PC one.

References.

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[12] General Plan of Kettős Körös Bridge at Békés (Designed by UVATERV)


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